The oceans and climate change

Raymond Najjar
Professor of Oceanography
Department of Meteorology and Atmospheric Science
The Pennsylvania State University
rgn1@psu.edu

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Outline

• The ocean’s role in the climate system
• Impacts of anthropogenic CO₂ emissions on the ocean
• Future climate scenarios
• Solutions
• Past environmental successes
• What you can do
The ocean’s role in the climate system
The seasonal temperature *range* (temperature of warmest month minus temperature of coldest month) is much smaller over the ocean than over land.

Data from the Japanese Reanalysis Project (1979–2004)
The Gulf Stream has a large impact on surface temperature.
The Gulf Stream keeps Northern Europe relatively warm

Departure of air temperature from its longitudinal (east–west) average (°C)

Most of the heat from global warming is going into the ocean

Change in Earth's Total Heat Content

Ocean Heating
Land + Atmosphere + Ice Heating

Change in total heat content since 1961 ($10^{21}$ Joules)

skepticalscience.com after Church et al. (2011)

The ocean is the largest reservoir of carbon on Earth that readily exchanges with the atmosphere

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Size, Gigatons Carbon (IPCC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>38,100 GtC</td>
</tr>
<tr>
<td>Soils and Vegetation</td>
<td>2,410 GtC</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>760 GtC</td>
</tr>
<tr>
<td>Ocean Sediments</td>
<td>1,750 GtC</td>
</tr>
<tr>
<td>Permafrost</td>
<td>1,700 GtC</td>
</tr>
<tr>
<td>Fossil Fuel Reserves</td>
<td>1,940 GtC (max. est.)</td>
</tr>
</tbody>
</table>

Oceans absorb carbon dioxide from the atmosphere, creating carbonic acid in the waters.

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \\
\text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{CO}_3^{2-} \leftrightarrow 2\text{H}^+ + \text{HCO}_3^- 
\]

**Sources**
- 34.7 GtCO₂/yr
  - 86%
- 5.5 GtCO₂/yr
  - 14%

**Sinks**
- 17.9 GtCO₂/yr
  - 44%
- 11.5 GtCO₂/yr
  - 29%
- 9.2 GtCO₂/yr
  - 23%

**Budget Imbalance:**
- 4% (the difference between estimated sources & sinks)
- 1.6 GtCO₂/yr
Impacts of anthropogenic CO$_2$ emissions on the ocean
Sea level is accelerating

Global Mean Sea Level Change

- Adjusted Tide Gauge Data
- Satellite Radar Altimetry

- 0.6 mm/yr (1900–1930)
- 1.4 mm/yr (1930–1992)
- 3.4 mm/yr (1993–2020)

http://www.columbia.edu/~mhs119/Sealevel/
“Sunny day” flooding in Miami

Photo source: Grist
Corals bleach—lose their symbiotic algae—when they are stressed

Photo of a fire coral that experienced severe bleaching in the 2016 mass bleaching event. The Ocean Agency / XL Catlin Seaview Survey / Richard Vevers.

Degree heating weeks are a bit complicated. First you compute the mean annual cycle in SST at monthly resolution. Second, of these 12 months, you find the month with the highest mean SST and you call it the maximum monthly mean (MMM) SST. The bleaching threshold is 1 deg C above the MMM. Third, you look at the past 12 weeks and find all of the half-week periods in which the 50-km SST is above the threshold. Call the exceedance DT. For each half week period, you multiply DT by 0.5 weeks. Then you add up all of these products to get DHW. Source: https://coralreefwatch.noaa.gov/satellite/education/tutorial/crw24_dhw_product.php
Record high ocean temperatures intensified Harvey and increased its flooding rains on land.

“Harvey could not have produced so much rain without human-induced climate change”

Trenberth et al. (2018)


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\[ \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{CO}_3^{2-} \leftrightarrow 2\text{H}^+ + \text{HCO}_3^- \]

Formation of \( \text{H}^+ \) is ocean acidification.
Future climate scenarios
Three possible emissions futures ...

... lead to very different climate futures

Simulated changes in global-mean sea level

Solutions
The cost to install solar has plummeted

Source: Bloomberg New Energy Finance & pv.energytrend.com
Renewables are cheap!

Costs of new electric power plant installations in dollars per megawatt-hour

<table>
<thead>
<tr>
<th></th>
<th>2018</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>60.143</td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>112.189</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>41.74</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>29.56</td>
<td></td>
</tr>
<tr>
<td>Solar</td>
<td>38.44</td>
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</tbody>
</table>


What if we kept our cars parked for trips less than one mile? In the US, each year we would save

- $900 million in fuel and maintenance costs
- 2 million metric tons of CO₂ emissions

Walkable & bikable communities are healthier and cleaner

https://www.epa.gov/greenvehicles/what-if-we-kept-our-cars-parked-trips-less-one-mile
What you can do
Energy Innovation and Carbon Dividend Act

THE BIPARTISAN CLIMATE SOLUTION

H.R. 763

This bill will drive down America's carbon pollution and bring climate change under control. It is:

- EFFECTIVE
- GOOD FOR PEOPLE
- GOOD FOR THE ECONOMY
- REVENUE NEUTRAL

Citizens' Climate Lobby

https://citizensclimatelobby.org/energy-innovation-and-carbon-dividend-act/
Paris Climate Conference 2015

Agreement to keep global warming well below 2.0 °C (3.6 °F)

Image source: www.cop21paris.org/
Past environmental successes
“Smog episodes”

October 1948: Pollution from zinc mills in Donora, PA combined with a temperature inversion, leads to 20 deaths

Source: Donora Smog Museum
This is happening much less often than it used to because ...

- Ozone: 28%
- NO₂: 52%
- CO: 82%
- SO₂: 83%
- Lead: 89%

Median change in US: 1980-2010

Data source: www3.epa.gov/airtrends

ThinkStock
The Clean Air act reduced emissions and created $170 - $430 billion per year in health benefits—all while energy use went up and costs went down!

Good news: the ozone hole is shrinking!

https://ozonewatch.gsfc.nasa.gov/statistics/annual_data.html

NASA image

https://ozonewatch.gsfc.nasa.gov/statistics/annual_data.html
Why? Because levels of (human-produced) chlorofluorocarbons are dropping.

Montreal Protocol adopted

https://www.esrl.noaa.gov/gmd/hats/combined/CFC11.html
Cleanup of the Delaware River allowed the return of the American Shad

July Oxygen at Ben Franklin Bridge

https://www.nj.gov/drbc/edweb/shad-return.html
Take-home messages

1. The ocean is a moderator of the climate
2. Anthropogenic CO\textsubscript{2} emissions have negative impacts of the ocean: warming, sea-level rise, and acidification
3. Human-induced climate change will continue to occur regardless of emissions scenario; further adaptation is necessary
4. The climate of the mid century and beyond is very sensitive to the emissions scenario
5. Solutions are at hand
6. Good science, policy, and business practices have gotten us out of environmental messes before
References


